Decision Models and Ecosystem Management

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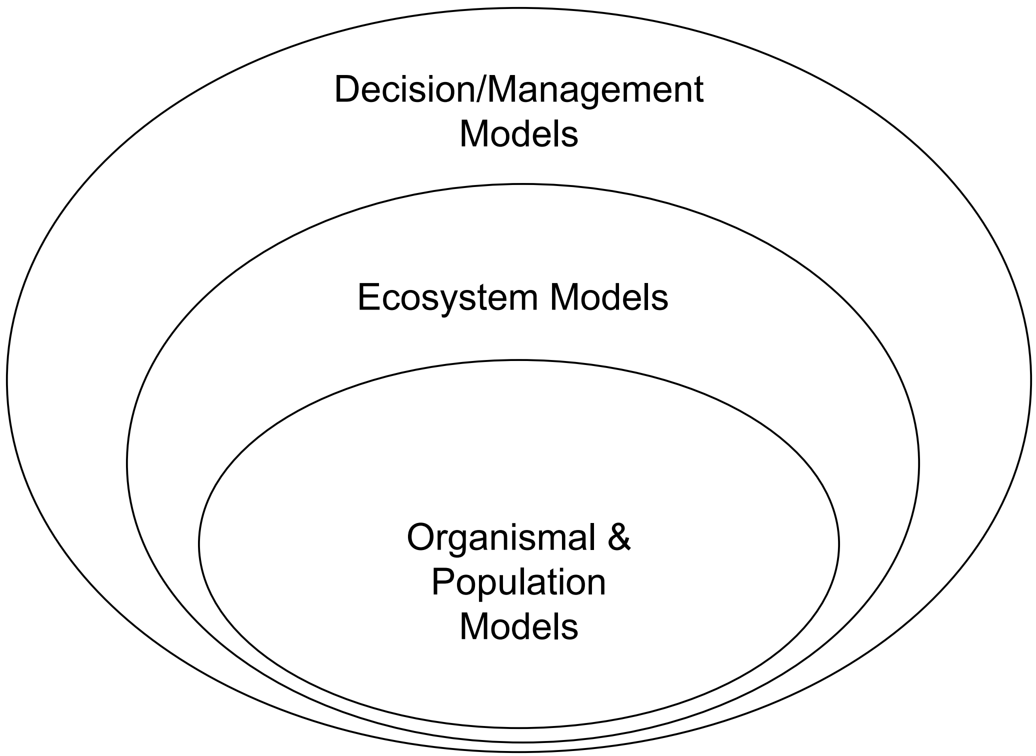
The Egg Model of Ecosystem Management



Decision Models

Ingredients

- System state and dynamics
- Decision variables
- Objective

Some Types

- Bayesian decision
- Classical optimization
- Fuzzy logic, SWOT, etc.

Salmonid Habitat Restoration

- ESA Listings (27 ESUs)
- > $110 mn on habitat restoration (2001) in CA
- Threats to habitat
  - Sediment
  - Passage barriers
  - Temperature
  - Water diversion, mining, etc.

Model 1: Stochastic + Dynamic

Question: What's the best way to manage road erosion under uncertainty?

Model 1: Problem Characteristics

- Possible treatments:
  - Maintain *status quo* road *(cheap, high-risk)*
  - Upgrade road *(moderate expense and risk)*
  - Remove road *(expensive, low-risk)*
- State variables:
  - Landslide volume
  - Surface erosion volume
  - Crossing-failure volume

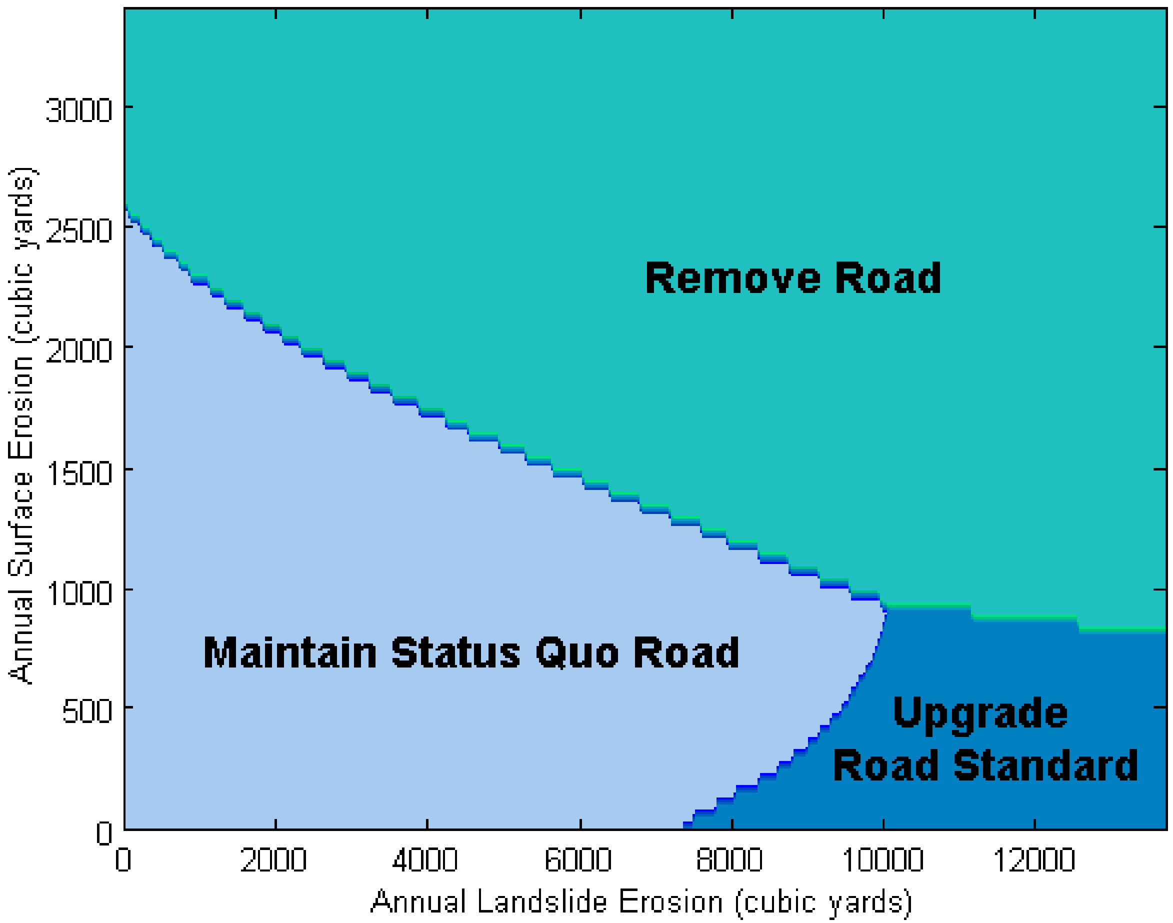
Model 1: A Stochastic Dynamic Program

$$main\,problem \quad V_1(x_t) = \min_u \{ \; C_1(x_t) + \frac{1}{1+\rho} E[V_1(C_1(x_{t+1})) \mid x_t, s=1], \;\; U + V_2^*(x), \;\; R_1 \}$$

$$sub-problem: \; V_2(x_t) = \min_u \{ \; C_2(x_t) + \frac{1}{1+\rho} E[V_2(C_2(x_{t+1})) \mid x_t, s=2], \quad R_2 \}$$

where	$V(x)$	= the expected present and future cost of optimal treatment
	x	= vector of erosion volumes
	u	= control
	$C_1(x)$	= annual road maintenance costs for *status quo* road
	$C_2(x)$	= annual road maintenance costs for upgraded road
	ρ	= manager’s discount rate
	s	= 2 if the road has already been upgraded 1 if the road is still *status quo*
	U	= lump-sum cost of road upgrade
	R_1	= lump-sum cost of *status quo* road removal
	R_2	= lump-sum cost of upgraded road removal

Model 1: Results



Model 2: Spatial + Deterministic

- *Question:* Which barriers to remove?

Model 2: A Nonlinear Integer Program

Goal: maximize the increase in upstream accessibility, subject to a budget constraint.

$$\textit{max}\ z = \sum_j v_j \left[\prod_k \left(p_k^o + \sum_i p_{ik} x_{ik}\right) - \prod_k p_k^o \right] \quad \text{(sum of increases in passability-weighted stream length)}$$

subject to

$\sum_i x_{ij} \leq 1$	$\forall\ j$	(only one project can be chosen)
$\sum_j \sum_i c_{ij} x_{ij} \leq b$		(only \$b can be spent in total)
$x_{ij} \in \{0,1\}$	$\forall\ i$	(projects are all-or-nothing)

where

i = project index

j = barrier index

k = barrier index for barriers downstream of j (and including j)

v = habitat above barrier j until next upstream barrier

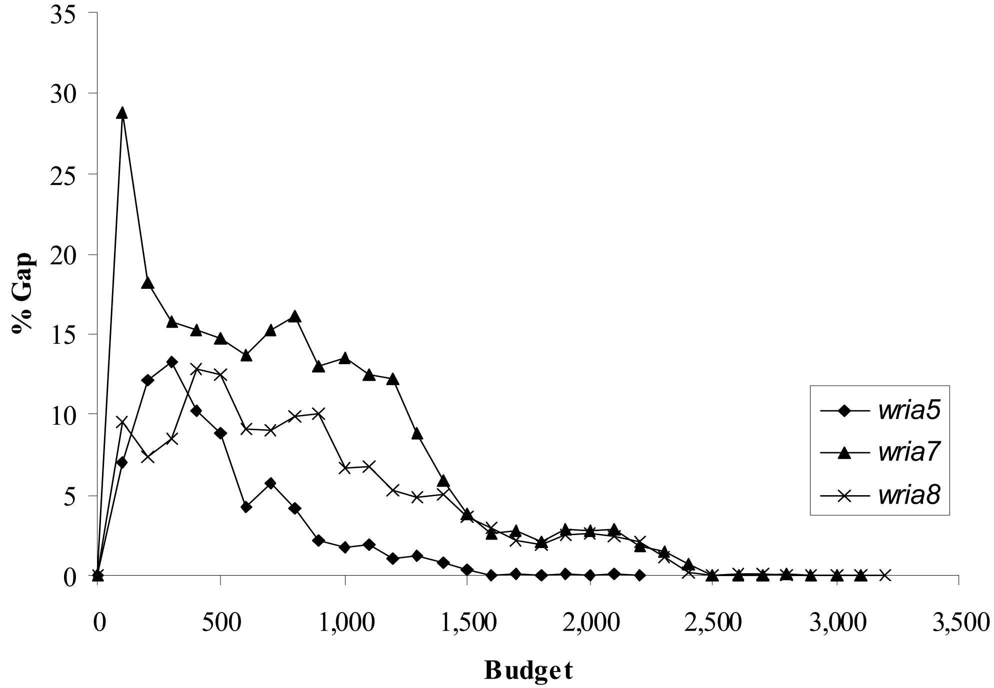
p = percent passability index for each barrier

x = project variable (do or don't)

c = project cost

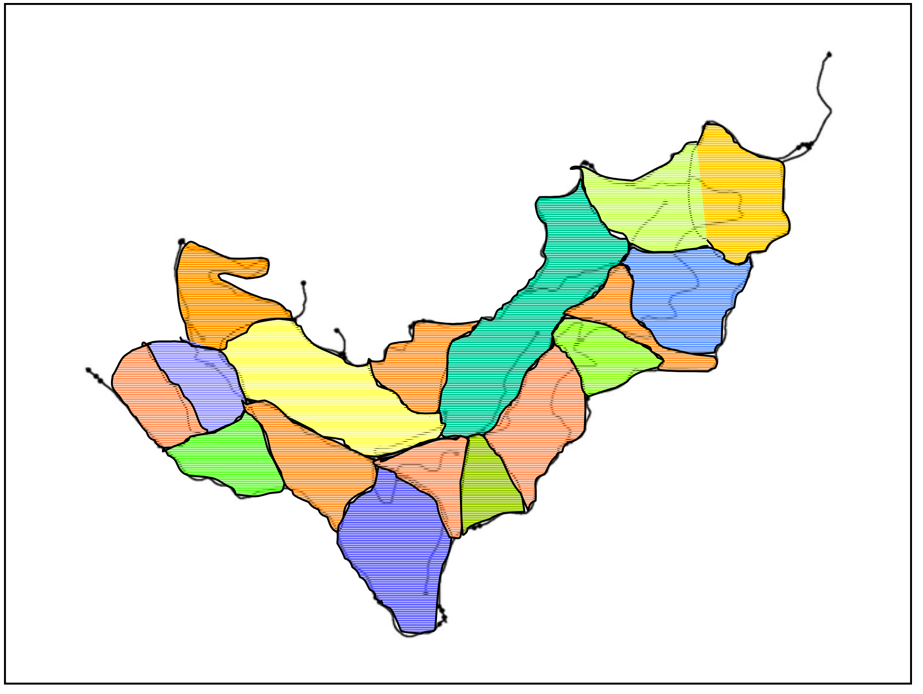
b = total budget

Model 2: Results



Percent deviation from optimum of a sorting and ranking procedure for three watersheds in western Washington, as a function of budget.

Model 3: Spatial + Deterministic + Dynamic

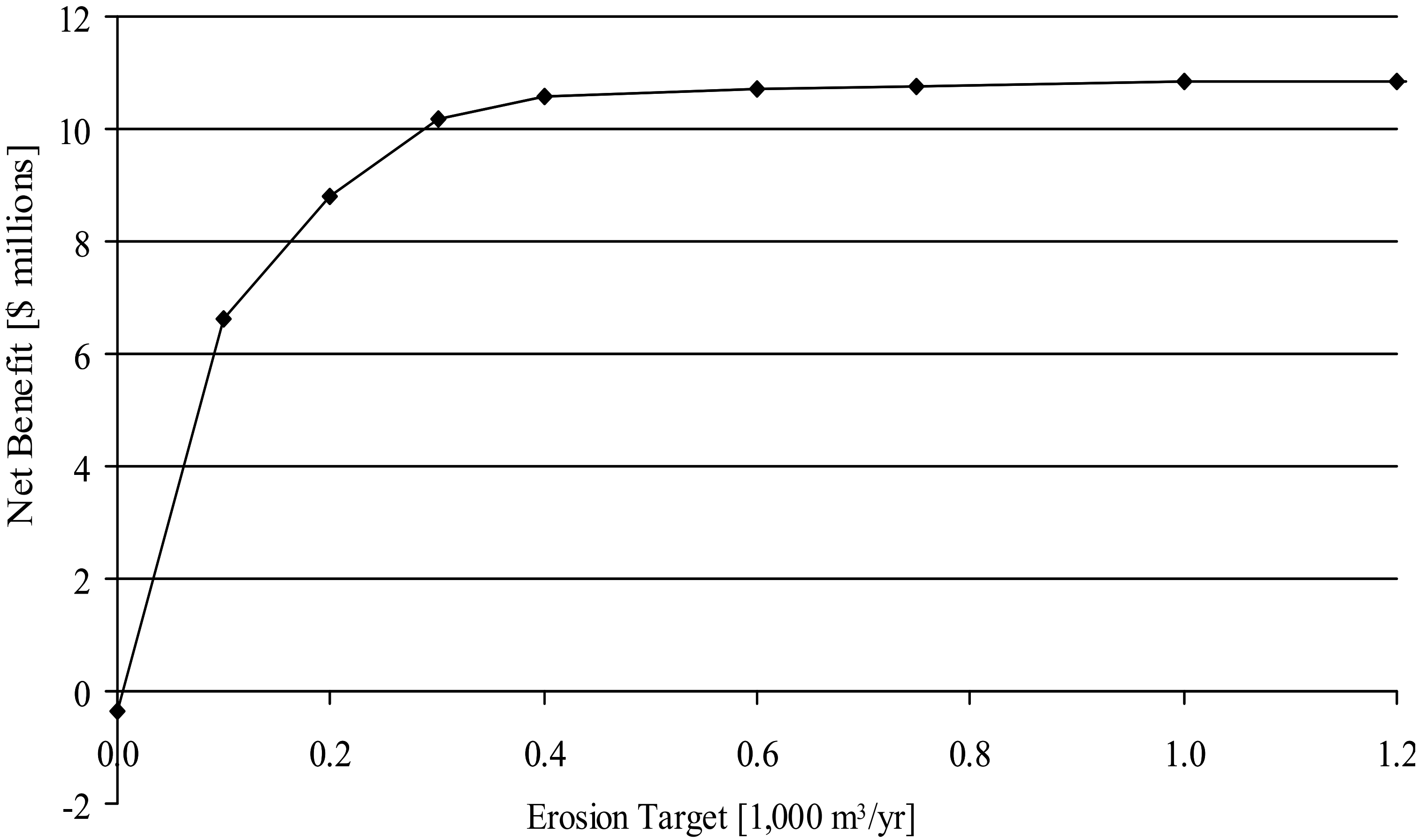


- *Question:* What's the best combination of road treatment and timber harvest?

Model 3: A Mixed-Integer Program

- Goal: Max net benefit
- Benefits: Timber and access
- Costs: Logging, transport, and erosion control
- Constraints:
  - Max erosion
  - Access and traffic flow
  - Inter-temporal

Model 3: Results



Model 4: Lake Erie Ecosystem

- 17 species (3 commercially targeted)
- Decision variables: TACs, phosphorus level
- Objective variables:
  - Recreational: walleye density, mean sport catch
  - Consumption: PCB concentrations
  - Ecological: total biomass, walleye/percid ratio, piscivore/planktivore biomass ratio, native/invasive biomass ratio
  - Commercial: walleye, yellow perch, smelt biomass

Model 4: Lake Erie Ecosystem

- Objective = f(weights, utilities)
- Stakeholder involvement
  - **Discuss weights, objective function**
  - **Structure problem**
  - **View risks and trade-offs**
- Monte Carlo simulation of 100 years (per weight / decision candidate), keeping stochastic weather etc.
- Can invest in learning to reduce estimation risk via Bayesian learning

Assessment

- [Aside: Some things I didn’t talk about:]
  - Different types of uncertainty
  - Decision theory
  - Information acquisition
  - Adaptive management
- In principle, ecosystem applications are not so different
- Information demands are high
- But even if an ecosystem is completely characterized, you still have to define or agree on objectives